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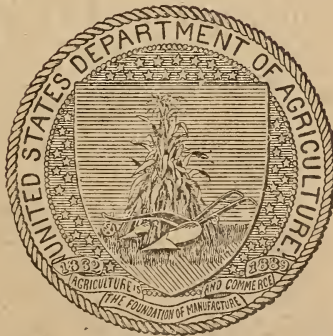
Issued March 23, 1912.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN NO. 84.
MILTON WHITNEY, Chief.

MODIFICATION OF THE METHOD
OF MECHANICAL SOIL
ANALYSIS.

BY

C. C. FLETCHER AND H. BRYAN.



WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1912.

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LETTER OF TRANSMITTAL.

UNITED STATES DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS,

Washington, D. C., November 11, 1911.

SIR: I have the honor to transmit the manuscript of an article entitled "Modification of the Method of Mechanical Soil Analysis," by Messrs. C. C. Fletcher and H. Bryan, of this office. The article is accompanied by detailed working drawings showing the construction of improved apparatus used in the Bureau of Soils in making soil analyses. The information given should be of value to other soil investigators, and I therefore recommend its publication as Bulletin No. 84 of this bureau.

Respectfully,

MILTON WHITNEY,
Chief of Bureau.

HON. JAMES WILSON,
Secretary of Agriculture.

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MODIFICATION OF THE METHOD OF MECHANICAL SOIL ANALYSIS.

INTRODUCTION.

The mechanical analysis of the soil, as carried out in the Bureau of Soils, has been devised as an expedient method of obtaining a quantitative statement for the classification of soils on a physical basis. There exists a close relationship between the mechanical composition and most of the physical properties of soils, although the exact nature of the relationship is not yet satisfactorily known. Many attempts have been made to classify soils upon the basis of some physical property, but to measure any physical property of soils without regard to the mechanical composition would disregard those relations of most importance in the practical management of soils. The physical properties of a soil are dependent upon the structure of the soil as well as upon the mechanical composition. The organic matter present influences both composition and structure. Hence we have a number of dependent variables of whose relations to one another we yet know very little. But the mechanical composition of any particular soil remains reasonably constant, so that it has been adopted as a basis for classification until the relationship existing between mechanical composition and the physical properties of the soil have become better known. The classification of soils on this basis is of agricultural value, as certain obvious characteristics attach to clays, loams, sands, etc., as classes.

In the mechanical analysis the soil is divided into a number of different grades of particles, whose dimensions lie between definite limits, and the percentage by weight of each of these grades is determined. In general, the basic methods used in mechanical analysis are separation of different size particles by sifting in the case of the larger particles, and by sedimentation (usually in water) in case of the smaller ones. Various successful modifications have been devised, based on these methods.

Mechanical analysis may be of service in other fields than in the classification of soils. Any industry in which a substance is to be reduced to a given degree of fineness may find the method described useful. Graphite, limestone, fertilizers, etc., may be separated by this method.

LIMITS OF MECHANICAL GRADES.

The names and sizes for the several separates which have been adopted by the Bureau of Soils are:

	Millimeters.	
Fine gravel.....	2	—1
Coarse sand.....	1.0	—0.5
Medium sand.....	0.5	—0.25
Fine sand.....	0.25	—0.1
Very fine sand.....	0.1	—0.05
Silt.....	0.5	—0.005
Clay.....	0.005	—9

This system of grouping the soil particles is purely arbitrary, and the particles are seldom separated naturally and easily into grades. The more grades into which a soil is correctly divided the better the idea of the value and behavior of the soil obtained, but the work and time required for separation is also greatly increased; especially is this true in making a large number of grades of the finer particles. The system used in the Bureau of Soils has sufficient divisions to meet every ordinary requirement, without unduly lengthening the time of analysis.

SCOPE OF WORK DONE BY THE BUREAU OF SOILS.

At the present time the collection of soil samples in the bureau numbers over 20,000, a majority of which have been subjected to mechanical analysis. Nearly 2,000 are being added annually. In order to perform the work quickly and accurately special apparatus is necessary, and the following equipment has been found to answer the purpose. Although part of the apparatus is found in every laboratory, everything required for the mechanical analysis of soils will be discussed for the benefit of persons wishing to install a complete laboratory for this particular purpose. A detailed description, with drawings of the parts of the shaking machine, the sieves, and the centrifuge, will be found at the end of this bulletin.

EQUIPMENT AND APPARATUS.

SHAKING MACHINE.

The shaking machine (Pl. I) consists of a carriage holding six trays supplied with places for eight bottles each. The carriage runs on a V-shaped cast-iron track and is driven by a one-fourth horse-power motor. The motor is connected with the carriage by two gears and an eccentric shaft. The small gear is a 12-tooth one, made of fiber and attached to the shaft of the motor; the other gear has 120 teeth, made of cast iron, and is attached to the end of the eccentric

shaft. Connecting the eccentric with the carriage is a shaft with split bearing. The shaft is not a solid rod, but is divided at its center. A plunger with a steel head works in a brass case, and on either side of the head is a spring of 15 pounds compression, used to lessen the recoil. The motor is controlled by a rheostat and has a speed of 1,000 revolutions per minute, which the gears bring down to 100 revolutions per minute.

CENTRIFUGE.

For the separation of the finer particles some form of centrifuge is advisable; one run by any of the different forms of power may be used. When current is available, it is probably most satisfactory to use an electric motor. The centrifuge used in this laboratory has a one-fourth horsepower vertical-shaft electric motor, carrying a spider holding racks for eight tubes. The motor is started with a small rheostat, shown in the illustration at its right. Around the machine is a strong wooden guard, designed to minimize the danger to the operator from the breaking of glass tubes. The motor is attached by its base to the table, and the top of the machine is left open for convenience in filling or emptying the tubes, etc. A photograph of the centrifuge is shown in Plate II and detailed drawings at the end of the bulletin.

MICROSCOPE.

A compound microscope is used for determining the sizes of the soil particles. A very convenient instrument is supplied with an eyepiece micrometer so calibrated that one division equals 0.005 mm., the superior limit of the clay, and 10 divisions equal 0.05 mm., the upper limit of the silt particles. A high power objective is unnecessary, as the presence or absence of appreciable amounts of silt in the clay is easily discerned without it. An eyepiece micrometer calibrated to have two divisions equal 0.005 mm. is sometimes of special utility. With this arrangement it is possible to divide the clay into two portions with a lower limit of 0.0025 mm. for smallest particles. Ordinarily this is not done, as the greatly increased amount of time required for this separation is not justified by the additional information gained. It is usually considered advisable to depend entirely upon the coarse adjustment of the microscope, on account of the great gain in speed.

DISTILLED WATER UNDER PRESSURE.

For many purposes a system of distilled water under pressure is of service. While it is possible to use ordinary filtered water in effecting separation, the amount of material in solution will be enough in many cases to impair the results. An analysis of the tap water at Washington, D. C., 5.2 liters (an amount often used on one

sample during mechanical analysis) gave 0.425 grams solid material in solution, which is 8.5 per cent on a 5-gram sample of soil. Distilled water under pressure is used in stirring up the particles on the bottoms of the bottles and tubes. A jet of water from a capillary glass tube is directed upon the sediment and quickly brings the particles into suspension. A distilled-water system which has been found convenient for this purpose consists of a glass bottle of 12-liter capacity, with two attachments, one to suction for filling, and one to pressure to give the requisite force to the jet. A pressure of about 12 pounds to the square inch best meets the requirements. When a large pressure system is not available, a water or electric compressor will be found serviceable. It is not satisfactory to use an ordinary air pump and tank, because the pressure varies, and it is difficult to obtain a uniform suspension of the soil particles in the tubes and bottles. In the system used the water is carried through block tin pipes under the floor of the laboratory and up through the center of the table carrying the centrifuges. There it is distributed to each machine.

SAND SIEVES AND MECHANICAL SIEVE SHAKER.

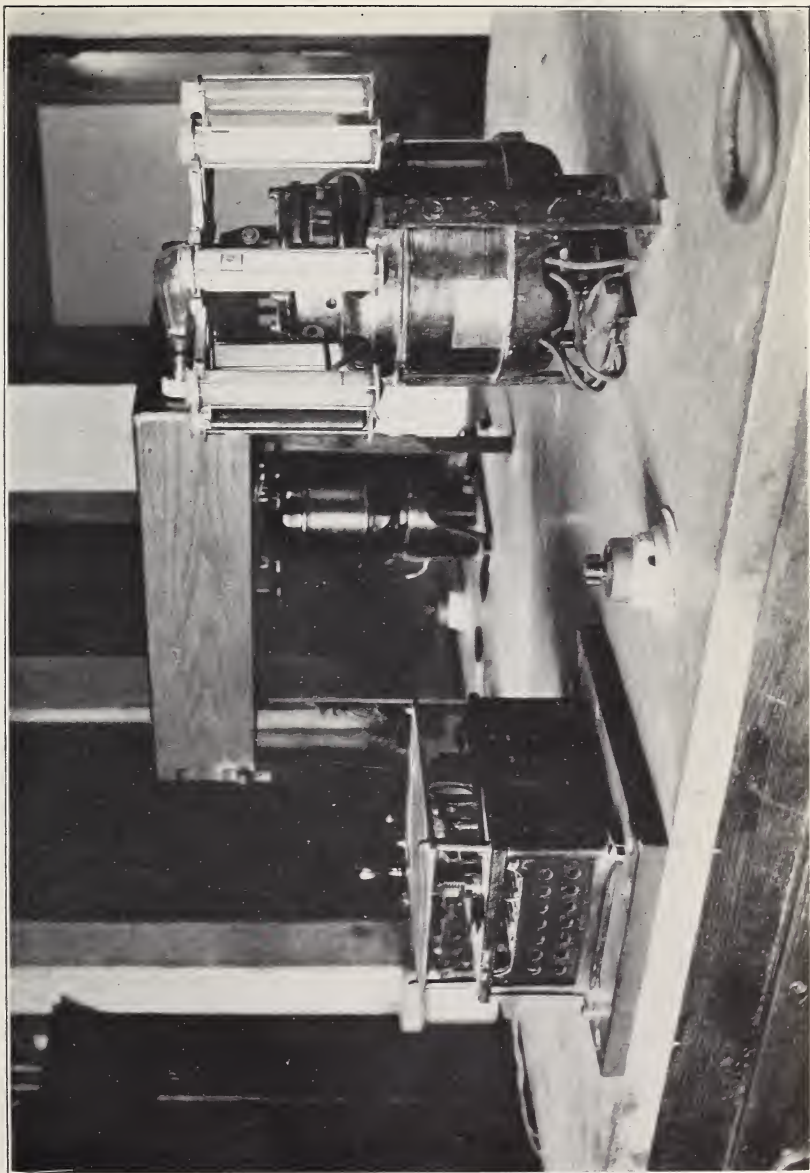
In separating the sands a nest of four sieves is used. The top and second sieves have brass plates with circular perforations of 1 and 0.5 mm. diameter, respectively, and the third and bottom ones have silk bolting cloth of No. 5XX and No. 13XX of double extra heavy quality, giving holes of practically 0.25 and 0.1 mm. diameter, respectively. The sieves are of brass, fitted one upon another, and have a closed base section to retain the very fine sand. The sections with silk bolting cloth have removable bottom rings, making it easy to replace worn cloth. The set of sieves is operated by a shaking machine, consisting of a small electric motor with an eccentric horizontal shaft. Clamps hold the sieves in position and a spring presses them down upon the shaft, which on rotating gives them a rapid movement in a vertical plane. Working drawings and photographs (Pl. II, figs. 1 and 2) of the sieves and shaker are given.

MISCELLANEOUS APPARATUS.

The steam bath used is of copper, supplied with holes in the top of a size to fit small platinum dishes. It is advantageous to have the number of holes some multiple of 8. There are also spaces at the back to hold porcelain cups. The holes are fitted with porcelain rings. An ordinary gas hot-plate is employed for drying down the clay water. For final drying electric ovens maintaining a uniform temperature of about 105° C. are used. Electrically heated ovens have an advantage in that they can be safely run overnight.



SHAKING MACHINE.



CENTRIFUGE.

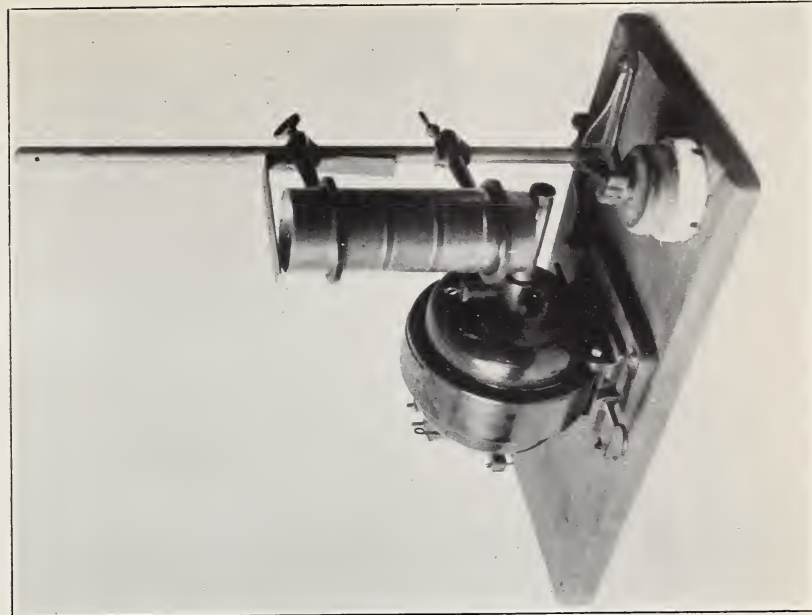


FIG. 2.—SHAKER IN POSITION FOR USE.

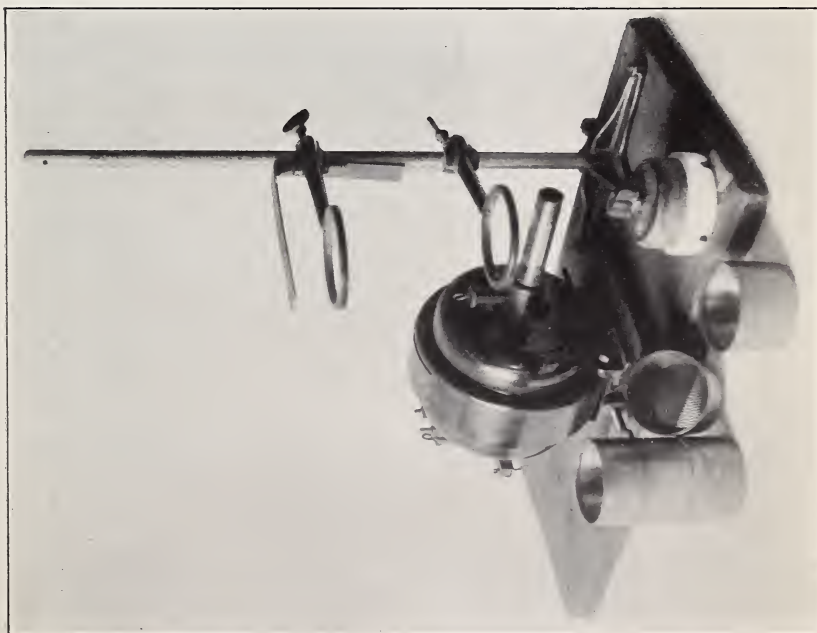


FIG. 1.—SAND SHAKER, SHOWING ARRANGEMENT OF SIEVES.

Two balances are employed—one with a 200-gram capacity for weighing sands and silts, and one with 500-gram capacity for the clay cups. Both the balances are sensitive to 0.001 gram, to which degree of accuracy all the weighings are carried out. The platinum dishes are small, round-bottomed ones, with a capacity of 50 c. c. The porcelain or enameled-ware cups and pitchers are the usual ones obtainable in any department store or camping supply house. The cups have a capacity of 550 c. c., width 9.5 centimeters, height 9 centimeters. The enameled-ware pitchers have a capacity of 2,500 c. c. The centrifuge tubes are $6\frac{3}{4}$ inches long, $1\frac{3}{16}$ inches internal diameter, and $\frac{1}{16}$ inch thickness of wall; the bottoms are made extra thick to withstand pressure but not heat. The tubes are carefully annealed.

METHOD IN USE AT PRESENT.

SAMPLING.

The samples collected in the field are sent in canvas sacks to the laboratory and are preserved in the bureau's collection in glass jars. Coming through the mail the soil becomes more or less air-dry, and heavy clay soils are often in very hard lumps. In getting a subsample, the whole sample is thoroughly mixed with a spatula until as uniform an appearance as possible is obtained. Then a smaller sample is obtained by quartering. The soil remaining is returned to the glass jar. The subsample is then passed through a 2-millimeter sieve; any lumps present are crushed with a wooden rolling pin, care being used not to grind any gravel into sand or to break up the coarser particles into finer ones.

In some soils, where the gravel and sand are composed of very soft rock fragments and the clay is in hard lumps, it requires great care to avoid crushing the gravel and at the same time to get the true amount of clay. The fine earth—material less than 2 millimeters—is placed in small circular, flat-bottomed aluminum dishes and dried for at least two hours in the electric oven. It is then cooled in a desiccator, 5-gram samples weighed out, and put in 8-ounce sterilizer bottles with 2 ounces of water and a few cubic centimeters of ammonia. In weighing out the final samples material is taken from different parts of the subsample to insure uniformity as far as possible. The spatula should get each time a portion containing material from the bottom of the dish to the top. If this precaution is not taken the heavier particles will not be in their proper proportion, as they tend to settle to the bottom of the dish. While 5 drops of ammonia have been shown to be sufficient (Bulletin 24, p. 22), inasmuch as in the progress of analysis the soil is washed again and again, each time reducing the amount of ammonia, it has been found ad-

visible to put in several cubic centimeters, and thus enough is left to keep the particles deflocculated until all the silt and clay are washed from the sand.

SHAKING.

The bottles containing the soil, water, and ammonia are put into trays and shaken by the mechanical shaking machine for at least seven hours. More time usually does no harm to the soil, but if left for too great a period of time the rubber stoppers may be eroded to an appreciable extent.

MAKING SEPARATIONS.

The eight bottles, numbered consecutively, are removed from the shaking machine and placed upright in the rack. The rubber stoppers are removed and examined for erosion; if the stoppers are badly eroded it may be necessary to repeat the analysis. Any soil material adhering to the stopper is washed back into the bottle with the jet, each of the eight soils is in turn brought into suspension by the use of the compressed water jet, and then sufficient time allowed for all the sands to settle. This time is determined by an examination with the microscope. In taking the sample for microscopic examination a small glass tube is employed and material is taken at a depth to which liquid will be removed by decanting. Thus, if 1 inch of material is to be left in the bottle, it is not necessary to take the material below that level. Usually if the contents of the eight bottles are stirred up in order, by the time the last bottle is reached the first is ready to decant. Liquid from bottle No. 1 is poured into centrifuge tube No. 1, etc., and when the tubes are filled the centrifuge is run until there are no silt particles left in suspension. This is determined with the microscope. If time is no object, every soil should be examined, but usually only the soil containing the most clay is tested and the time for the whole set gauged by that necessary for this soil. The clay suspension is poured from tube No. 1 into pitcher No. 1, from tube No. 2 to pitcher No. 2, etc., and the silt at the bottom of the tubes is brought into suspension by the use of the jet. After centrifuging again another microscopic examination is made to determine the absence of silt particles in suspension. The liquid is decanted as before. This process is continued until the separation is complete. As a rule, in making the earlier separations the larger particles are held up by smaller ones; consequently as the separation nears completion it is possible to reduce the time before decanting. This is done in the sand-silt separation by stirring up a smaller number of samples at a time, and in the silt-clay separation by reducing the time of centrifuging.

The length of time will vary with the soil and speed of the centrifuge. Thus clay soils are almost invariably more difficult to separ-

rate than sandy soils, both in duration of centrifuging and in the number of times run before the separation is complete. With the centrifuge used in the Bureau of Soils the time usually varies from 10 down to 5 minutes or less, the number of times depending on the type of soil. The length of time for the complete separation usually approximates two hours for a very sandy soil up to eight or more hours for clay soils. The analysis is finished when the silt and clay are removed from the sand and the clay is separated from the silt.

As a matter of fact, it is impossible to get absolutely clean separations. It is possible in the sand-silt separation to balance up the sand poured into the silt by leaving silt in the sand, similarly with the silt-clay separation. Another method of balancing errors is to pour off silt, and so arrange the time that the largest-sized silt particles go over without any sand, and call the determination complete when no more silt can be poured over without also pouring over sand. Similarly in the silt-clay separation, the centrifuge is run as long as any clay can be removed from the silt without pouring over silt. The determination is considered finished when it is not possible to get more clay without pouring over silt. When the separation is complete the sands are in sterilizer bottles, the silt in the centrifuge tubes, and the clay in the porcelain pitchers. The sands are transferred from the bottles to small platinum dishes, dried by the steam bath and electric oven and cooled in a desiccator. The total weight of the sands is determined, after which the separation into five grades is made with the set of sieves. The dried sands are placed in the top sieve of the set and the whole nest placed in position for shaking. Separation into five grades is usually effected by three minutes' shaking. Each of the sands or the residues in the sieves and bottom is weighed; the total weight should come within 10 milligrams of the initial weight. These five weights give the amounts of the five grades of sand in the soil sample. The silts are transferred from the tubes to platinum dishes, dried, cooled, and weighed similarly to the sands.

DETERMINATION OF THE CLAY CONTENT.

In the method of mechanical analysis of soils originally devised and used in the Bureau of Soils¹ the amount of clay was determined—after the coarser particles had been separated by centrifuging—by evaporating the clay-water to small bulk in enameled-ware saucepans, transferring it to platinum, carrying completely to dryness, and weighing the residue. This method was found undesirable on account of the excessive time required for the evaporation, and because many dust particles and fragments cracked from the lining of the saucepans were incorporated with the clay and weighed

¹ See Bulletin No. 24, Bureau of Soils, U. S. Dept. Agr. (1904).

with it. In addition, the transfer from saucepans to platinum required much time and trouble and offered possibilities of loss. To avoid these difficulties, and especially to increase the rapidity of the work, it was decided to abandon the final transfer to platinum, and to complete the evaporation in enameled-ware dishes and weigh the clay in them without transfer. For convenience in weighing and to decrease the likelihood of entry of dust, the saucepans were discarded and much smaller enameled-ware cups were adopted. The cups have a capacity of about 300 c. c. and weigh about 180 grams each. This method has the disadvantage of requiring a much heavier balance, but the determinations seem none the less accurate, and a great saving of time has been effected. When speed is especially important the method may be still further shortened in the case of routine analyses by abandoning altogether the direct determination of clay and obtaining its percentage by difference. The error thus introduced is probably no greater than that involved in the centrifugal (or other) separation of the clay from the silt. The errors in both cases are generally within the limits of variation which may be expected between different samples of the same soil.

In 100 consecutive analyses taken at random from the recent files of the Bureau of Soils the variations between the percentage of clay as directly determined and those obtained by difference range between 0 and 2.28 per cent. In two cases the variation is over 2 per cent; in three cases, between 2 per cent and 1.5 per cent; and in six cases between 1.5 per cent and 1 per cent. In all other cases the variations were less than 1 per cent.

It is probable that in many cases the determination by difference is the more accurate, as all errors due to access of dust or to loss of clay suspension are thus avoided. Errors due to a not impossible change in the state of hydration of the clay are also eliminated. It is believed that in the vast majority of cases the method of determining clay by difference will be accurate within 1 per cent, and no greater accuracy is necessary or even desirable for purposes of soil classification. The saving of time is at least one-third, and this is well worth considering in routine laboratories where a large number of analyses are made. The direct determination must, of course, be retained for cases of special importance or where a check is necessary, and is probably also desirable for students and for small laboratories where a mechanical analysis is only made occasionally.

DIFFICULTIES ENCOUNTERED IN MECHANICAL ANALYSIS.

It is customary in making a mechanical analysis of a soil to disregard the organic matter, because, generally, it is distributed between the different separates, and the dry weight of organic matter in any one separate is not great. A high organic content makes a

mechanical analysis of a soil difficult. No satisfactory method of removing the organic matter has been devised, as any process which will get rid of the organic matter will change the character of the mineral soil particles. It is possible to remove the organic material by ignition, but in the process water of combination in the clay is driven off. The method used is to let the organic matter remain in the soil, trusting that it will be evenly distributed and that there will not be enough to interfere with the value of the analysis. It is not possible to make an accurate mechanical analysis of a muck or peat soil, and, as a rule, it should not be attempted with soils of this character.

Soils which disintegrate during analysis are occasionally found. In such cases the judgment of the analyst must be relied upon. The best procedure is to make an approximate analysis as rapidly and as accurately as possible. During every analysis some of the soil goes into solution, and under the present system is estimated as clay, whether the clay is determined by direct weight or by difference. As probably the major portion of the soluble material is absorbed by the clay, and as the clay, being composed of finer particles, also goes into solution more rapidly than the other separates, it is more reasonable to estimate the soluble matter as clay than as silt.

In some cases flocculation persists after the addition of ammonia. This difficulty is overcome usually by additional shaking or varying the concentration of ammonia. In deflocculating materials other than soils other agents than ammonia may be employed; for example, tannic acid for graphite powder.

Micaceous soils present a special problem in mechanical analysis. The particles as thin plates remain in suspension much longer than their apparent size under the microscope would seem to justify. In all cases the separations are made by size and not by weight; so a particle which has two dimensions larger than the superior limit of one grade is counted in the grade above, even though its weight may be far less than many of the particles in the lower grade. In sifting to obtain the sands, anything which will go through the sieve is weighed where it finally rests, even though it may have one dimension very much greater than the superior limit of that grade, and to be consistent the same idea is followed out in using the micrometer in the microscope. Any particle which would go through an imaginary sieve with circular perforations of 0.05 mm. and be held by a sieve of 0.005 mm. is counted as silt, and any particle which would go through the latter sieve would be counted as clay. This method leaves less to the personal equation of the operator than any other system devised.

Possibly the soils which cause the most trouble are those that contain a large percentage of particles near the limiting size between

very fine sand and silt, or between silt and clay. Often soils are encountered where it is almost impossible to say whether a considerable percentage of the sample should be classified as silt or clay. It is either coarse clay or fine silt. When this condition occurs, the only feasible course is to run the centrifuge for a longer period than necessary to get all the silt particles deposited. Then by gradually reducing the time of centrifuging and running for a considerable number of times, only a small amount of clay is decanted each time. Finally, when the time comes to determine between the fine silt and the coarse clay particles, all the fine clay particles have been removed and the determination is rendered less difficult.

DETAILED DESCRIPTION OF APPARATUS.

MECHANICAL SIEVE SHAKER AND SAND SIEVES.

The mechanical sieve shaker (Pl. IV, sheet 1) consists of sieves arranged to vibrate rapidly. The vibration is effected by the use of a $\frac{1}{8}$ -horsepower electric motor *A* mounted on a wooden base. Connected to the horizontal shaft of the motor is an eccentric brass sleeve *B* $2\frac{1}{2}$ inches long and $\frac{5}{8}$ inch in diameter, with the center hole $\frac{1}{8}$ inch off center. The set of sieves *C* is held on the eccentric by ring clamps *D*, with holes $2\frac{1}{4}$ inches in diameter, and standard *E* fastened to a wooden base. The sieves are forced down by the spring *F*. The power is controlled by switch *G*. The sand sieves *C* are $6\frac{3}{16}$ inches long and $2\frac{1}{8}$ inches outside diameter. Each one of the upper four sections is $2\frac{1}{8}$ inches outside diameter, $1\frac{1}{8}$ inches long, and 2 inches inside diameter. The upper two are supplied with brass plates with circular perforations 1 and 0.5 millimeter diameter, respectively, and the two lower with silk bolting cloth of No. 5XX and No. 13XX, double-extra quality, having holes of practically 0.25 and 0.1 millimeter diameter, respectively. The sieves are of brass, fitted one within the other, and have a closed base section, $2\frac{1}{8}$ inches outside diameter and $1\frac{3}{16}$ inches outside height; inside height, $1\frac{1}{16}$ inches. The brass perforated plates and the silk bolting cloth are held in position by accurately fitting removable rings $\frac{7}{16}$ inch long, 2 inches inside diameter, and $2\frac{1}{8}$ inches outside diameter.

CENTRIFUGE.

The centrifuge (Pl. VII, sheet 4) consists of a $\frac{1}{4}$ -horsepower vertical-shaft electric motor, carrying a spider holding rack for eight tubes. The motor *A* makes 900 revolutions per minute at highest speed, but lower speeds may be obtained by a rheostat control. The brass spider *B* is keyed to the shaft of the motor and held in place by a nut. The spider is $12\frac{1}{4}$ inches in diameter, $\frac{1}{2}$ inch thick, and with hub 2 inches wide, $1\frac{1}{4}$ inches in diameter, and with a $\frac{5}{8}$ -inch

hole. Attached to the spider by two steel screws *C* are eight baskets *D*, $6\frac{1}{4}$ inches long and $1\frac{3}{4}$ inches in diameter. These baskets consist of two brass plates; the top plate is $1\frac{3}{4}$ inches in diameter, $\frac{1}{8}$ inch thick, and with a $1\frac{1}{4}$ -inch hole. In use the hole in the bottom plate is covered with a felt pad. The plates are connected by three steel wires $\frac{1}{8}$ inch in diameter and $6\frac{1}{4}$ inches long, riveted to the plate at each end.

SHAKING MACHINE.

The carriage *A* of the shaking machine (Pl. V, sheet 2, and Pl. VI, sheet 3) has the following greatest exterior dimensions: Length 30 inches, and height $19\frac{5}{8}$ inches. The base is 30 inches long, 15 inches wide, and 1 inch thick. The top is 20 inches long, 12 inches wide, and 1 inch thick. The frame or body of the carriage is $17\frac{5}{8}$ inches high, $10\frac{1}{2}$ inches deep, the ends of $\frac{3}{4}$ -inch material, and the partitions between the drawers of $\frac{1}{2}$ -inch lumber. The drawers *B* are $16\frac{1}{2}$ inches long, $10\frac{1}{4}$ inches wide, and $2\frac{1}{2}$ inches deep, outside measurement. The drawers are partitioned off into eight divisions, each division is $7\frac{5}{8}$ inches long, $2\frac{3}{8}$ inches wide, and $2\frac{1}{8}$ inches deep, inside measurement, giving sufficient space to hold one 8-ounce sterilizer bottle. The carriage is of oak wood, with the exception of the bottoms, and division of the drawers, which are of poplar.

The carriage runs on V-shaped cast-iron ways or tracks *C*, 20 inches long, $1\frac{1}{8}$ inches wide and $1\frac{1}{8}$ inches high. The portion of the track on which the carriage runs is 16 inches long; at each end the rim is slightly raised to make a pocket to catch excess of oil.

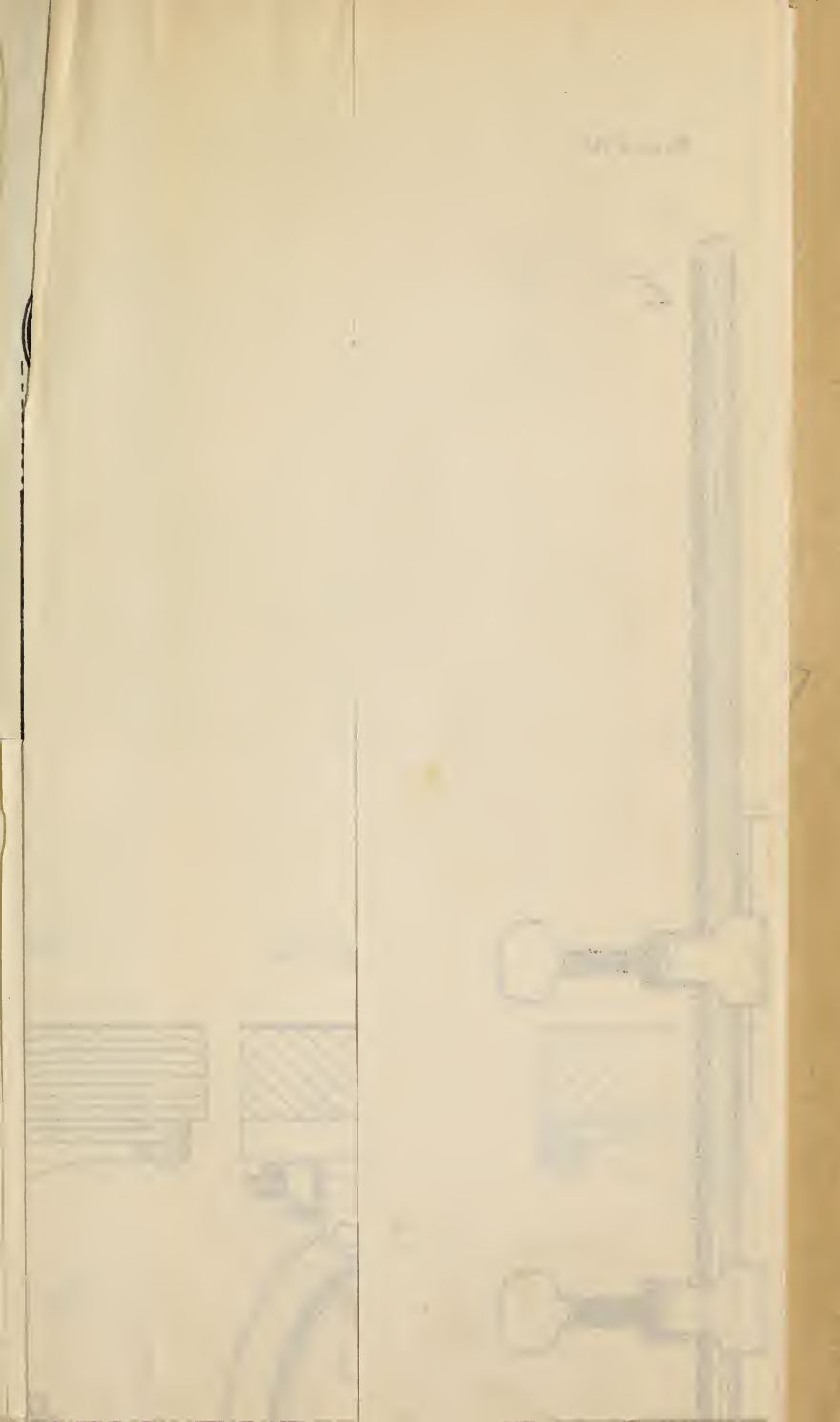
The machine is driven by an ordinary stock $\frac{1}{4}$ -horsepower motor *D*, making 1,000 revolutions per minute, and controlled by a rheostat. The motor is connected with the carriage by two gears and an eccentric shaft *E*. The gear attached to the shaft of the motor is 12-toothed, 10-pitch, fiber, which is meshed with a 120-tooth, 10-pitch, cast-iron gear, attached to the eccentric shaft running in two cast-iron standards *N*. The base plate is 6 inches long and 3 inches wide. The height is 7 inches. The bearing for the shaft is $1\frac{1}{2}$ inches in diameter and $1\frac{1}{2}$ inches long, with a $\frac{3}{4}$ -inch hole in it.

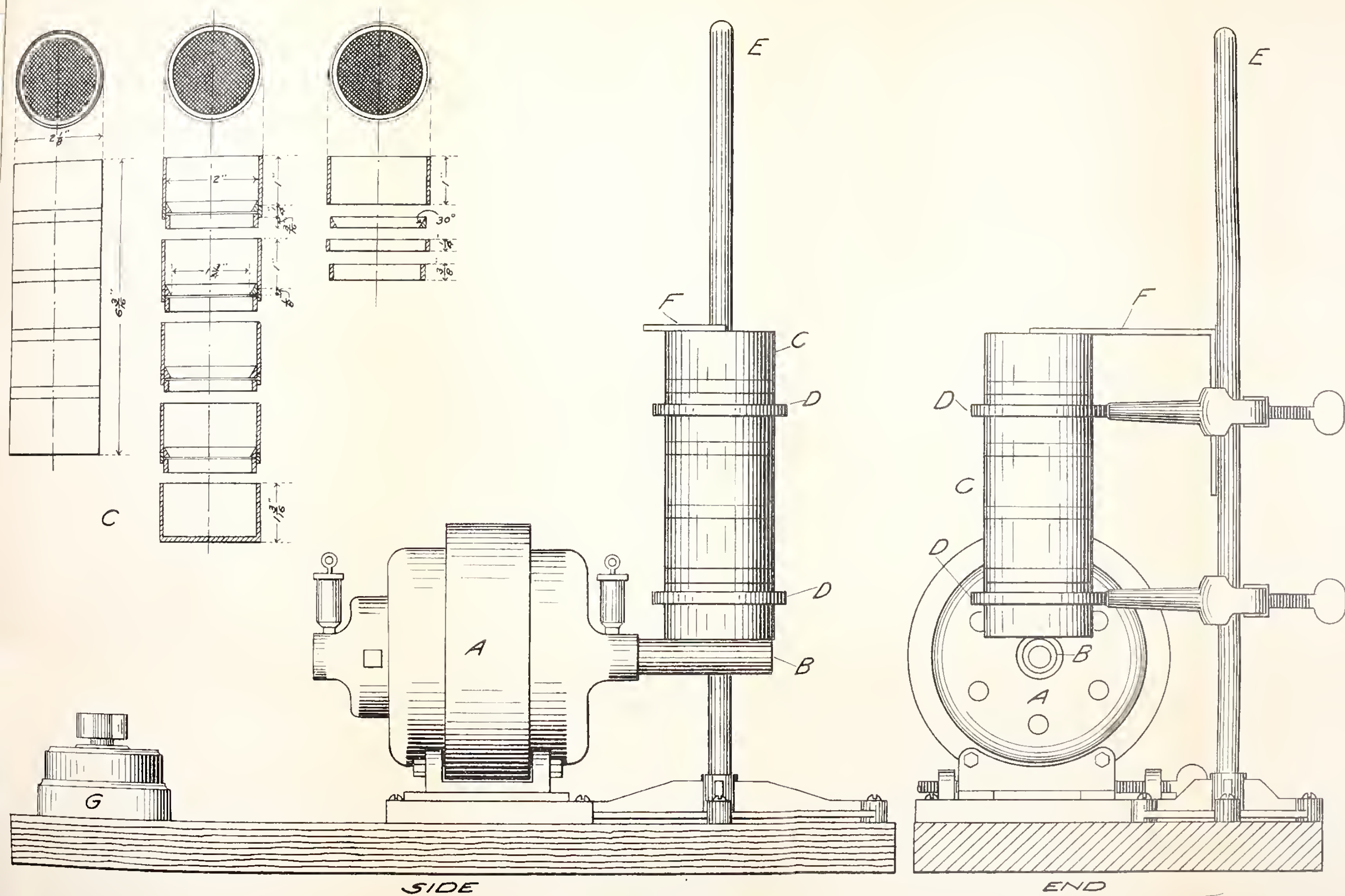
To obviate the danger of throwing the shaft out of alignment, the standards are bolted with $\frac{3}{8}$ -inch cap screws to a cast-iron base plate *O*, 12 inches long, 9 inches wide, and $\frac{5}{8}$ inch thick. The base plate is attached to the wooden base by four lag screws, $\frac{1}{2}$ inch in diameter. The machine is mounted on an oak board 45 inches long, 30 inches wide, and $1\frac{1}{2}$ inches thick. The eccentric shaft *E* is made of steel, 8 inches length over all, $\frac{3}{4}$ inch diameter, and set off center $1\frac{1}{2}$ inches. Connecting the eccentric with the carriage is the shaft *F*, 8 inches long, 1 inch in diameter, with a split head 2 inches in diameter and $\frac{1}{2}$ inch thick. On the other end is a plunger with a steel head $2\frac{1}{2}$

inches in diameter, $\frac{3}{4}$ inch wide, with a $\frac{3}{4}$ -inch hole, which is held to the shaft *F* with a lock nut *P*, $\frac{1}{2}$ inch thick, $1\frac{1}{4}$ inches in diameter, 16 threads, with $\frac{1}{2}$ -inch hole. This plunger works in a brass case *H* 6 inches long, 3 inches outside diameter, and $2\frac{1}{2}$ inches inside diameter. The head through which the shaft *F* works is brass, 2.575 inches in diameter, $\frac{3}{4}$ inch thick, with 1-inch hole, threaded on outside, 16 threads to the inch, to fit similar threads in the $\frac{3}{4}$ inch from the end of the inside of brass case *H*. The continuation of the shaft *Q* is attached to the end of the brass case on one end and to the cast-iron bearing *R* at the other end. The shaft *Q* is $5\frac{1}{2}$ inches long with a $2\frac{1}{2}$ -inch face $\frac{1}{2}$ inch long, and a body 3 inches long and 1 inch in diameter. The end working in *R* is $\frac{1}{2}$ inch thick, 2 inches long, with $\frac{1}{2}$ -inch hole through the center. On both sides of the piston, inside the brass case, are springs *I*, length 3 inches, outside diameter $2\frac{3}{8}$ inches, with about 15 pounds compression. Connecting the shaft *Q* and the carriage *A* is a cast-iron triangular block *R*, 6 inches long, 3 inches wide, and $4\frac{1}{4}$ inches high. The slot for *Q* is $\frac{5}{8}$ inch wide. The block is connected with steel pin *S* and with carriage by two $\frac{3}{8}$ -inch lag screws.

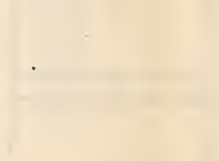
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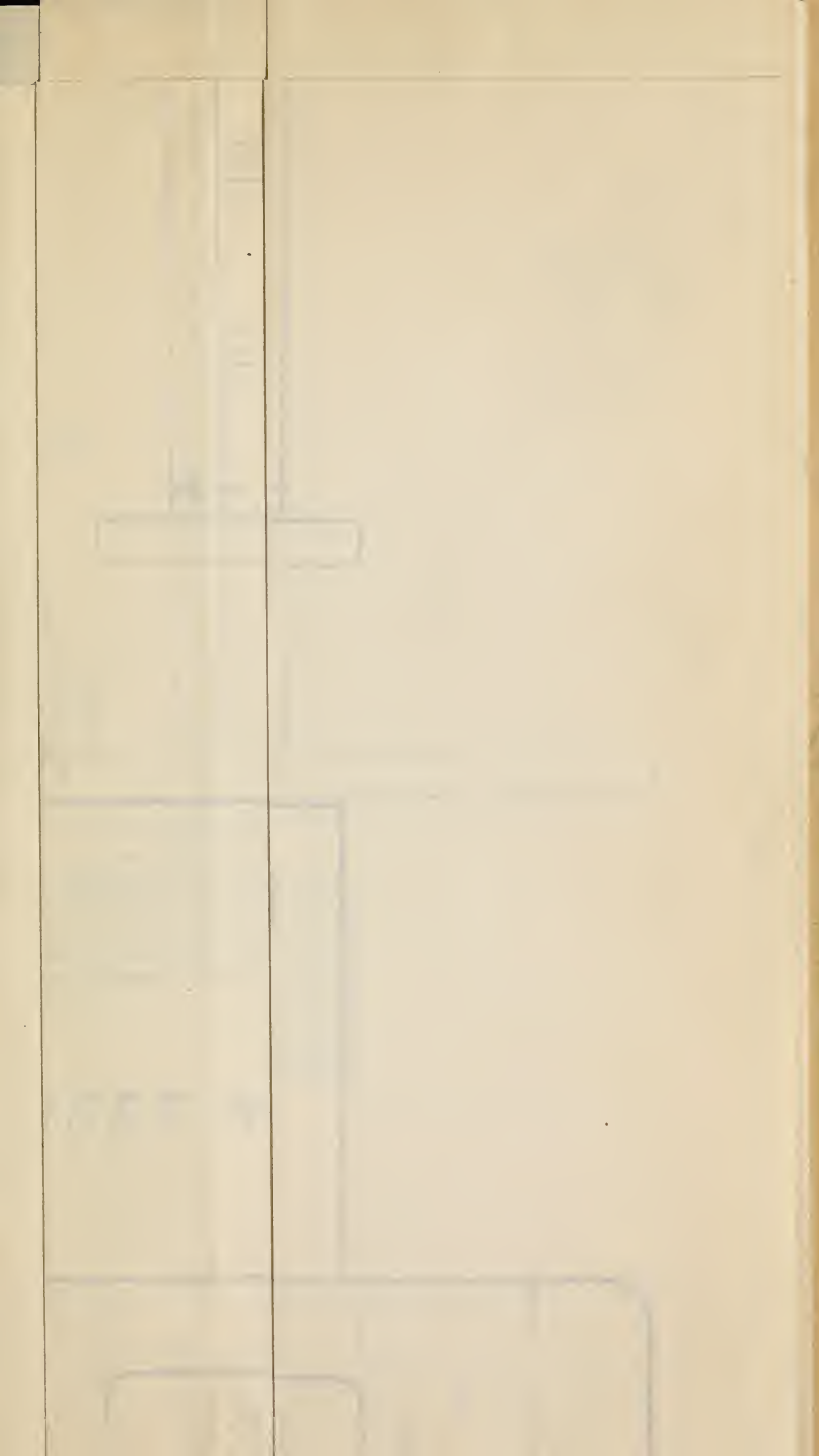


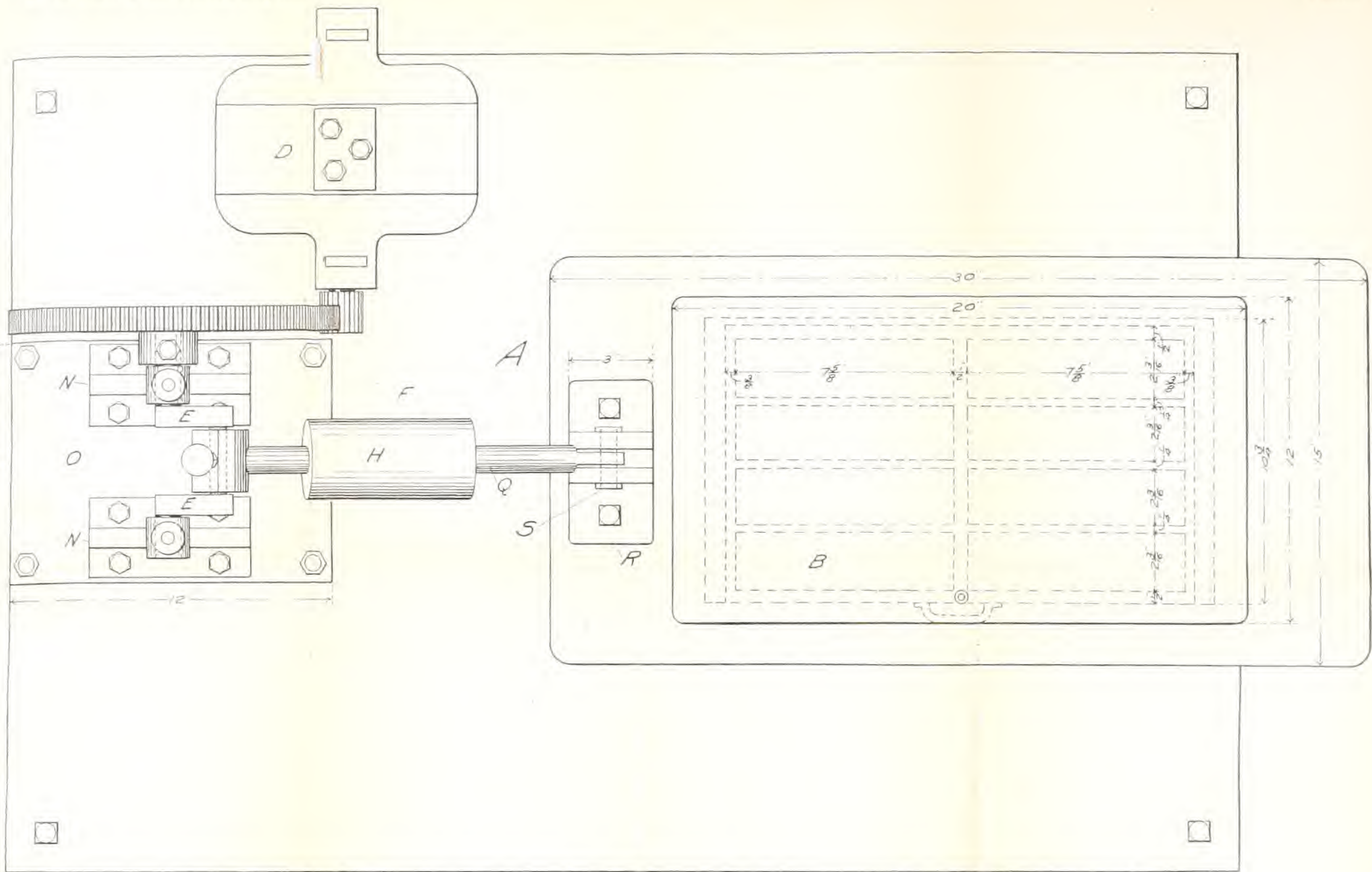




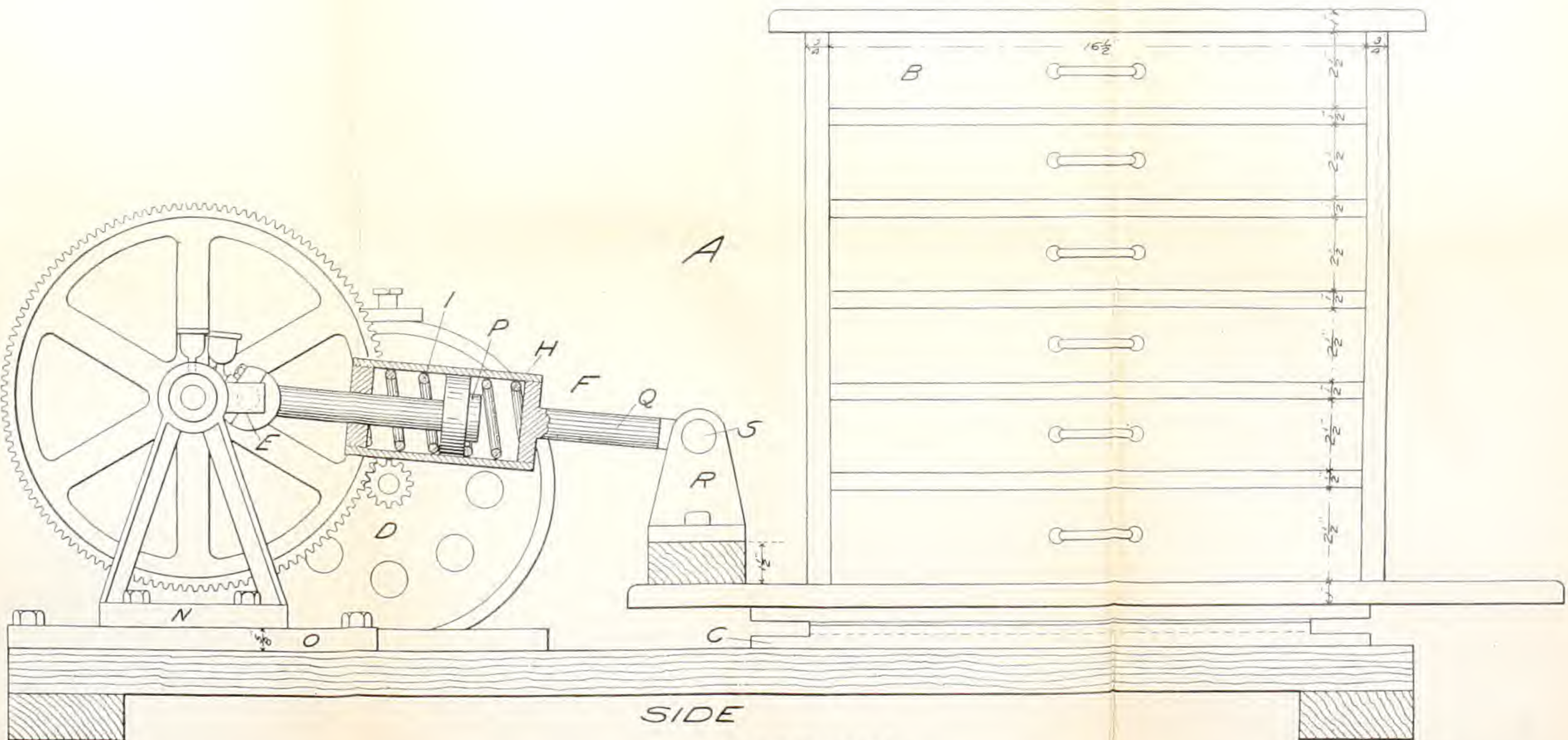
SHEET NO. 1



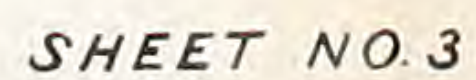




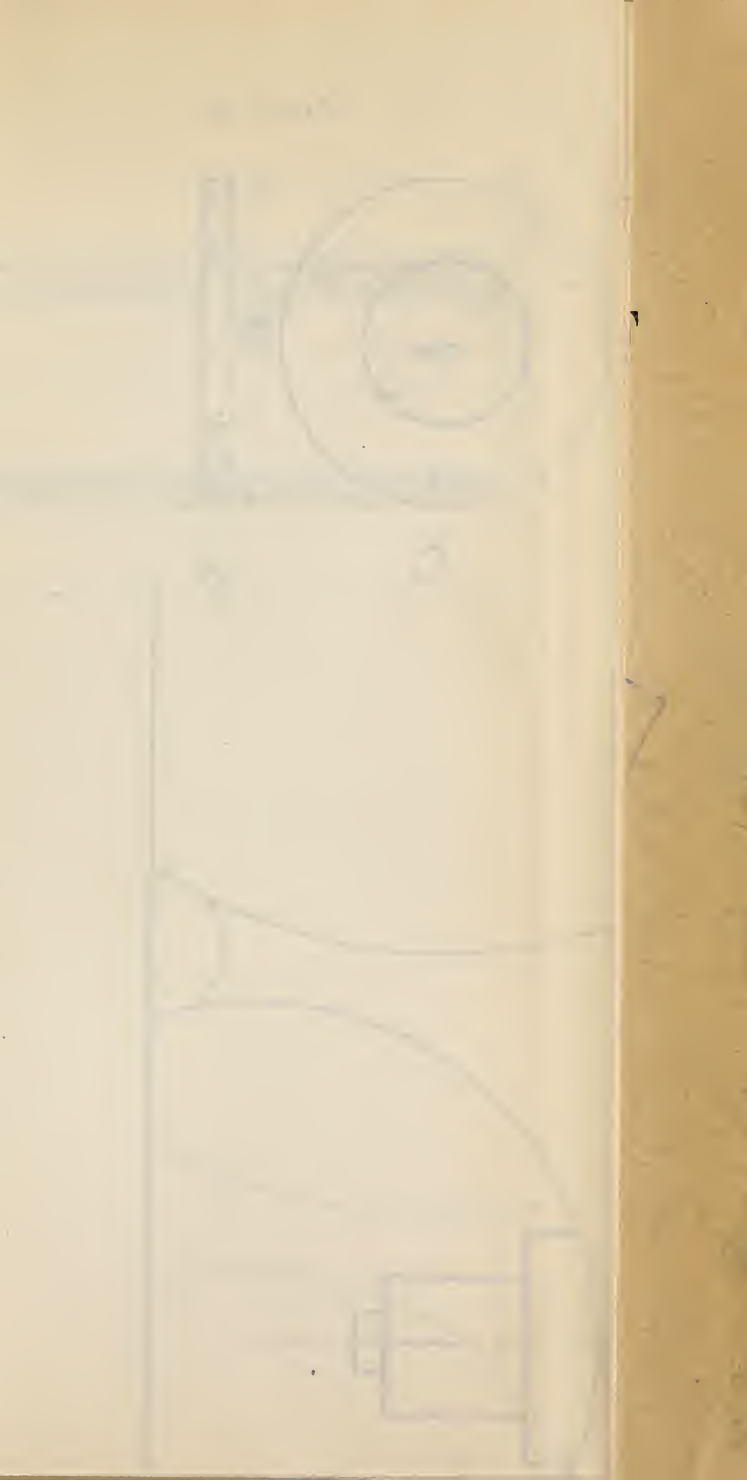
PLAN

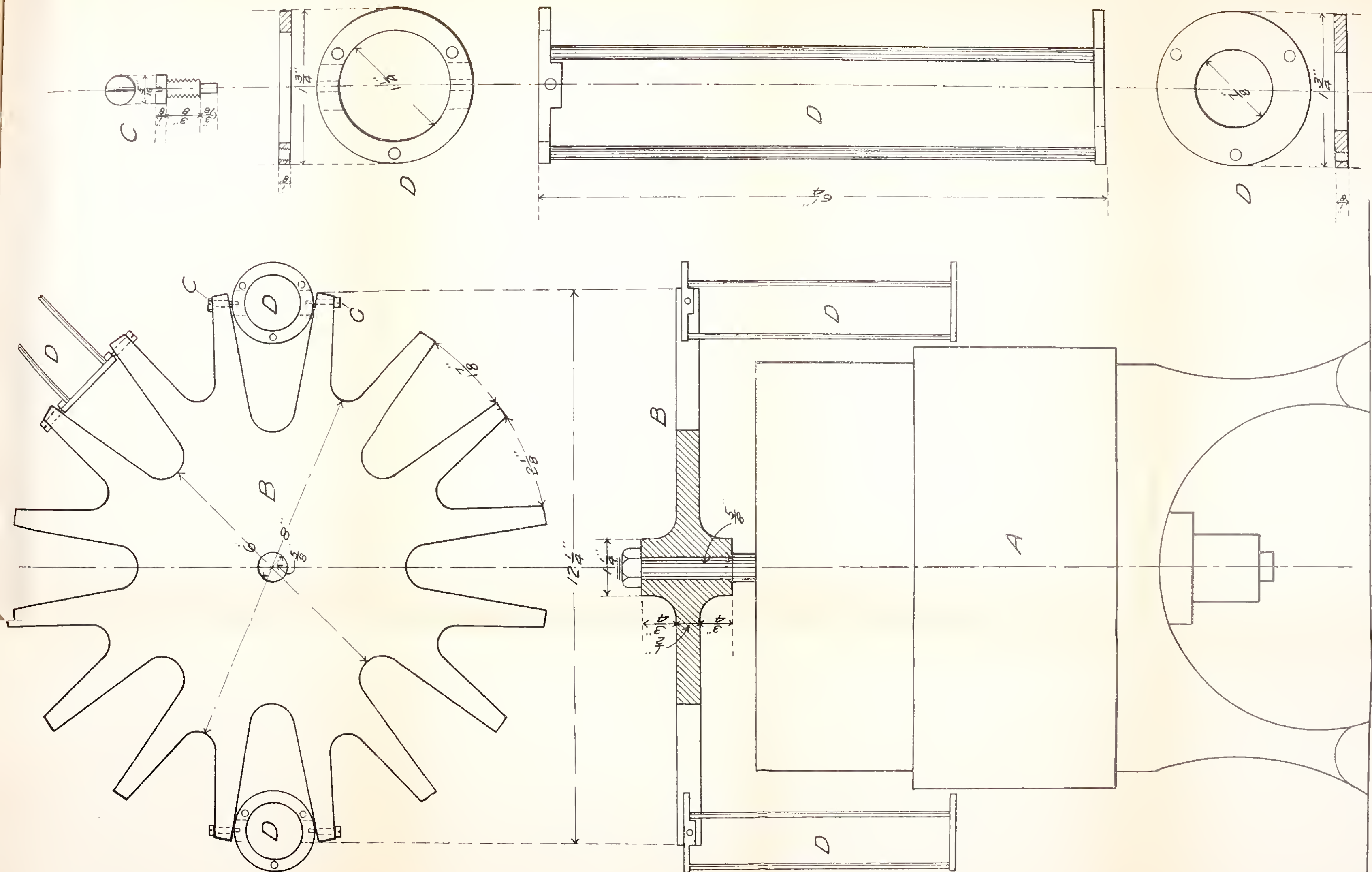


SIDE









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